LADEE Multi-Domain Simulation

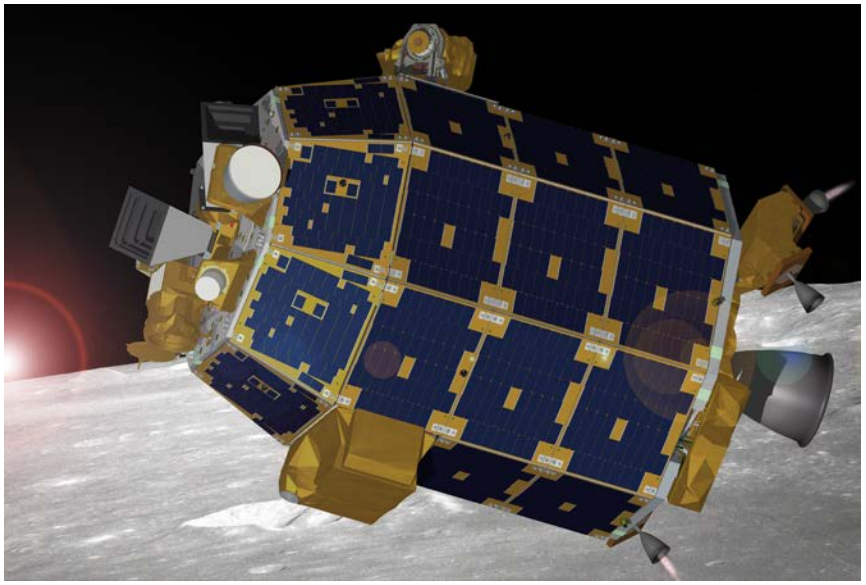
Danilo Viazzo
Cummings Aerospace
danilo.viazzo@cummingsaerospace.com

Nathan Benz
Millennium Engineering and Integration
nbenz@meicompany.com

CUMMINGS aerospace
a Native American Woman-Owned Small Business

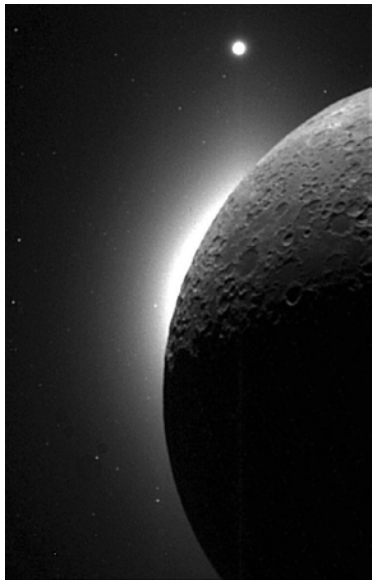
Millennium Engineering and Integration Company

Mission Overview

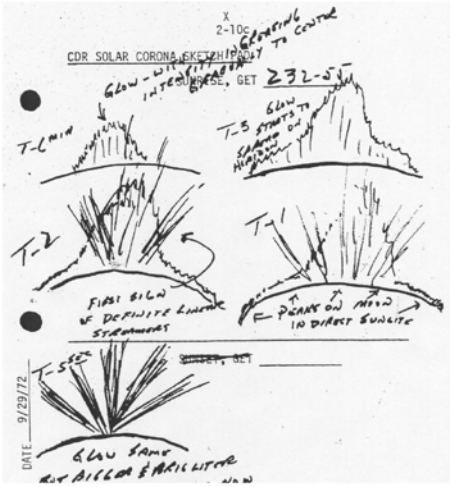


- Lunar Atmosphere and Dust Environment Explorer (LADEE) is a NASA mission that will orbit the Moon and its main objective is to characterize the atmosphere and lunar dust environment.
  - Low cost, minimal complexity and rapidly prototyped "common bus" design.
  - Model-Based Software Development

- Specific objectives are:
  - Determine the global density, composition, and time variability of the lunar atmosphere;
  - Confirm the Apollo astronaut sightings of dust jumps and diffuse emission
  - Laser Communications Demonstration: 622 Mbs Record download rate from the Moon!



Clementine spacecraft image of moon dust corona



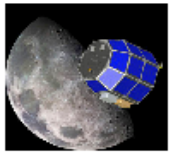
Gene Cernan's drawings of the lunar sunrise

Outline

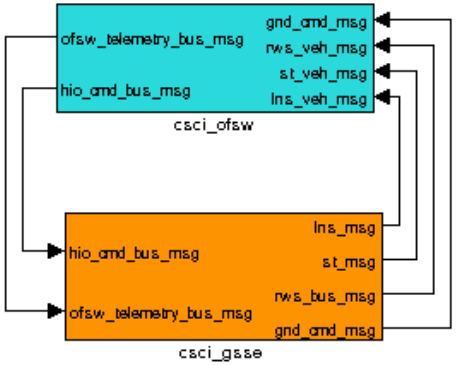
- Model Based Development
- Simulation Objectives
- Simulation Language and Structure
- Multi-Domain Elements
  - Simulation Interface
  - Electrical System Model
  - Thermal Model
- Lessons Learned

Model Based Development

- Scope
  - -Onboard Flight Software (Class B)
  - -Support Software and Simulators (Class C)
  - -Integration of FSW with avionics

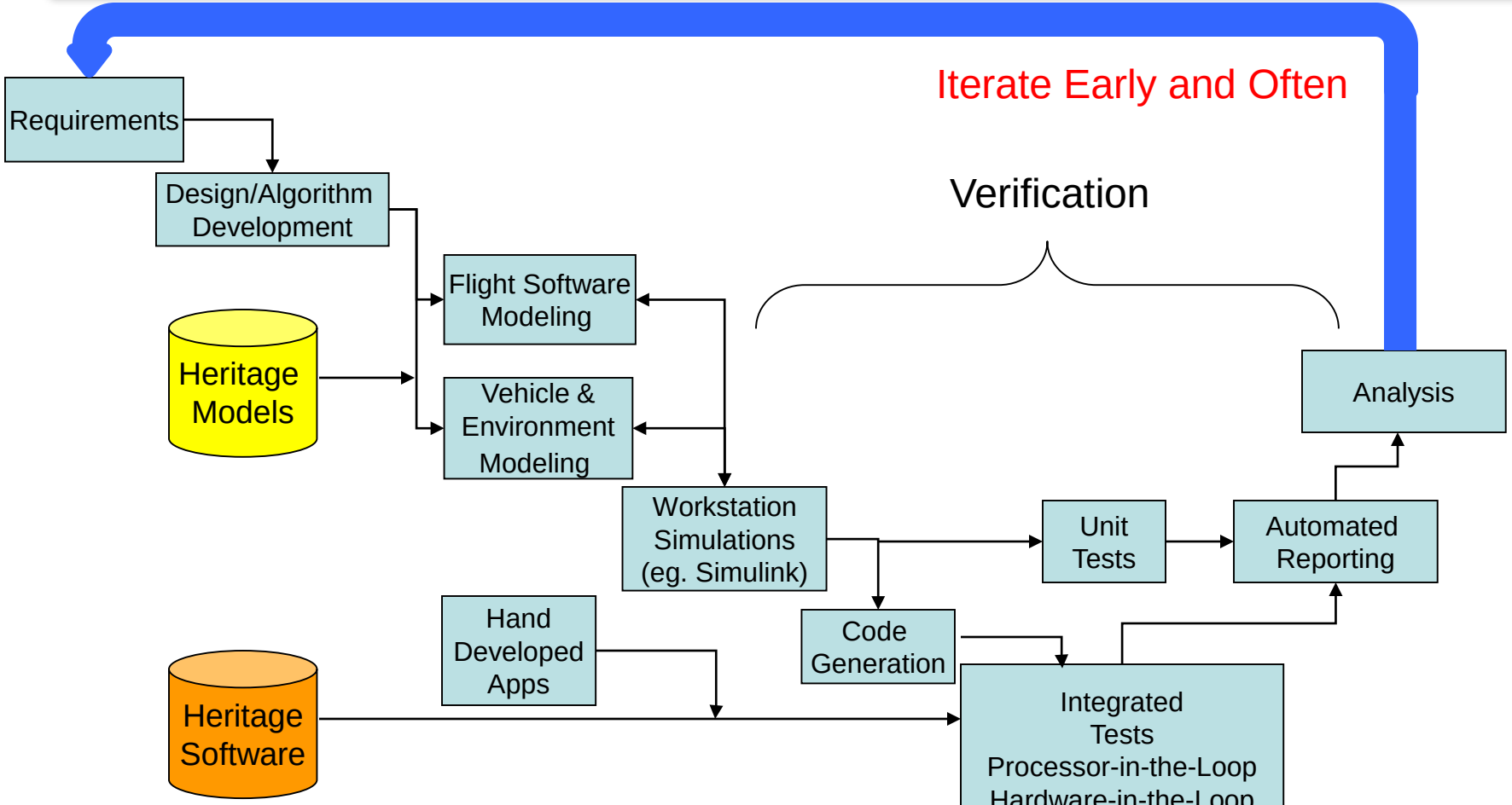

LADEE

- Guiding Documents
  - -NPR 7150.2 Software Engineering Requirements
  - -CMMI Level 2
  - -NASA-STD-8739.8 NASA Software Assurance Standard



- Development Approach
  - Model Based Development Paradigm (prototyped process using a “Hover Test Vehicle”)
  - 5 Incremental Software Builds, 2 Major Releases, 4 final sub-releases
    - 5.1: Defects found by I&T and 3DOF
    - 5.2: Defects found by Mission Operations Testing
    - 5.3: Final RTS set for Golden Load
    - 5.4: Platinum Load, uploaded during flight
- Leverage Heritage Software
  - GOTS: GSFC OSAL, cFE, cFS, ITOS
  - MOTS: Broad Reach Drivers
  - COTS: , VxWorks, Mathworks Matlab/Simulink & associated toolboxes

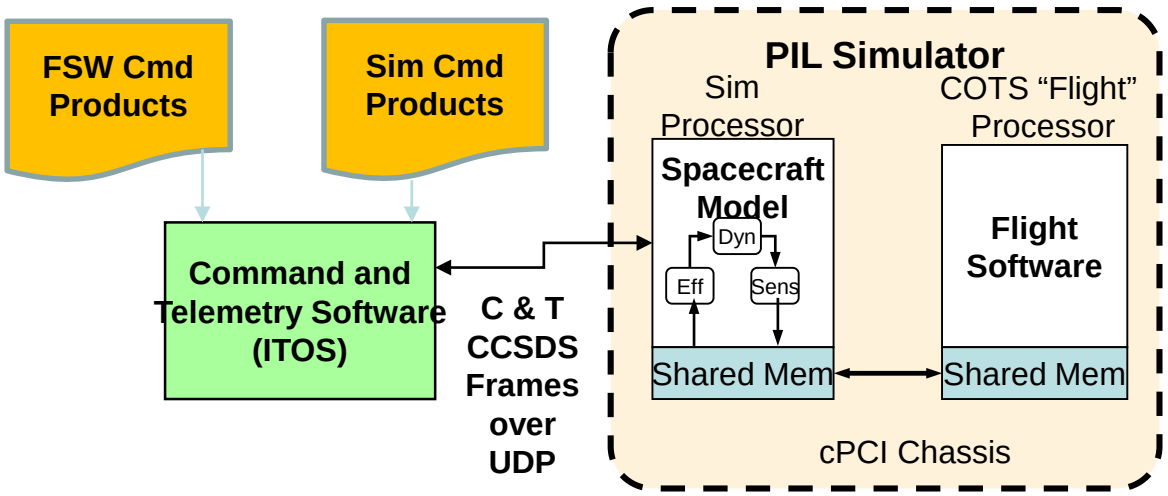
Model Based Development



- Develop Models of FSW, Vehicle, and Environment
- Automatically generate High-Level Control Software
- Integrate with hand-written and heritage software.
- Iterate while increasing fidelity of tests – Workstation Sim (WSIM), Processor-In-The-Loop (PIL), Hardware-in-the-Loop (HIL)
- Automated self-documenting tests providing traceability to requirements

Simulation Objectives

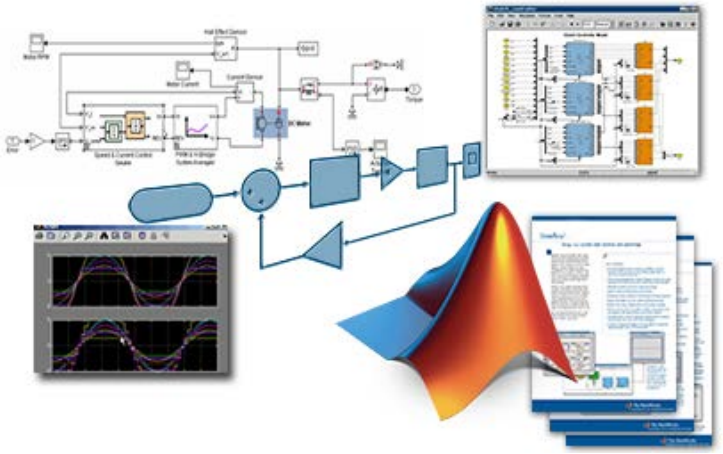
- Single Source Of Simulink Models
  - Superset of Models for Workstation Simulation
    - Onboard Clock Model
    - Onboard Stored Command Sequences
    - Spacecraft Commanding
    - Telemetry Collection
- Support Flight Software Development and Testing
  - Non Real-Time
    - Workstation Simulation
    - Monte Carlo
  - Real-Time
    - Processor In The Loop (PIL)
    - Hardware In The Loop (HIL)



- Support Mission Operations
  - Training
  - Flight

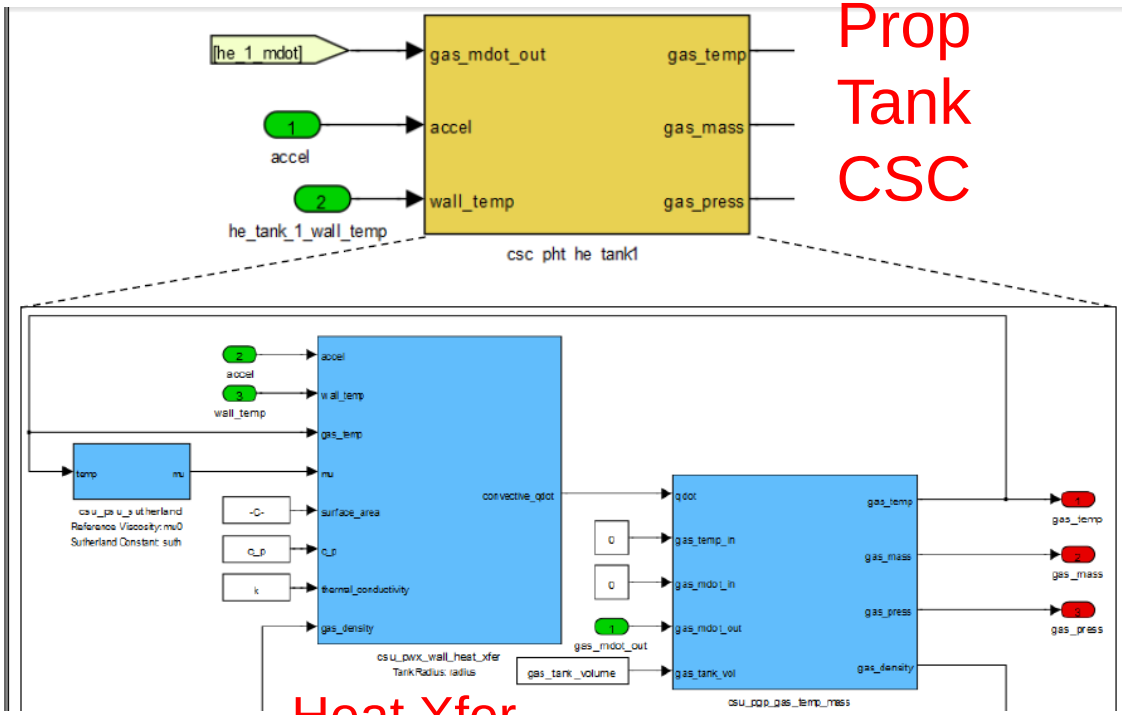
Simulation Language

- Simulation Tools
  - MATLAB/Simulink R2010b
  - Real-Time Workshop Embedded Coder
- Simulink
  - Native Blocks
  - Embedded MATLAB Blocks
    (MATLAB Function Blocks)
- MATLAB Scripts
- CSV Based Spreadsheet
  - Interface Definitions (Non-Virtual Bus Objects)
  - Subsystem Configuration Data
- External Data Files



Simulation Structure

- CSCI (Configuration Item)
  - Flight Software
  - Simulated Vehicle and Environment
- CSC (Component)
  - Vehicle Dynamics
  - Sensors
  - Actuators
- CSU (Unit)
  - Time Model
  - Gravity Model
- Utility Libraries
  - Quaternion Operations



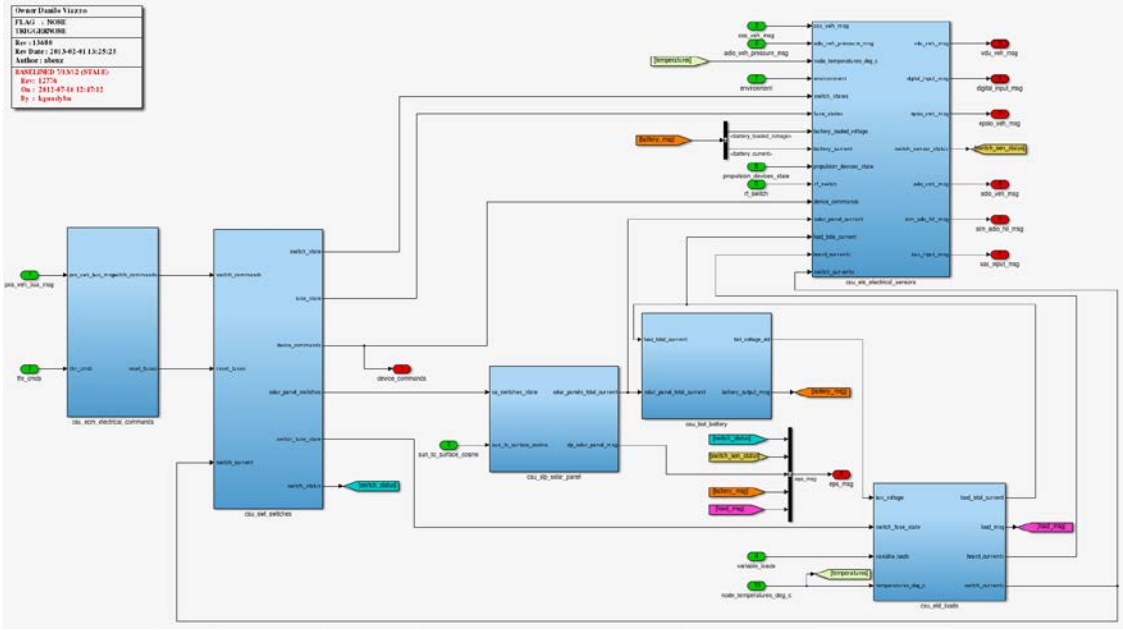
Simulation Interface

- Goal 1: Single Interface To Control Simulation
  - Workstation Simulation (WSIM)
  - PIL/HIL
- Goal 2: Simulated Spacecraft Command Interface Consistent With Ground Interface
  - Ground Commands
  - Onboard Command Sequences
- Implementation
  - MATLAB Based Parser for STOL Command Sequences
    - Spacecraft Command Sequences
    - Embedded Simulation Directives to Initialize Parameters
    - Both reduced to time based table for WSIM execution
  - Tunable Parameters
    - MATLAB Initialization Scripts to Define Default Values
    - MATLAB Override Scripts for WSIM
    - Memory Poke Mechanism to Override Parameters in PIL/HIL

```
2013-223-02:00:00 /EVS_USRMSG MESSAGE="Preparing for midnight obser

; change the fine pointing gains to fast for science operations
2013-223-02:00:00 /acs_select_fpc_cont_gain_set gain_set=FPC_FAST

; NMS midnight observation starting quaternion
2013-223-02:05:27 /acs_set_waypt_rt cmd_end_time=300, omega_x=0.000

; Reset the nms and ldex error counters so we can keep track
2013-223-02:09:16 /nmsio_resetctrs
2013-223-02:09:16 /ldexio_resetctrs

; Enable RTS's that will be used for payloads
2013-223-02:09:22 /NMSIO_RESETCTRS
2013-223-02:09:22 /pcs_man_cmd_id switch_id=PCS_NMS_PWR, state=PCS_
2013-223-02:09:24 /nmsio_activate
2013-223-02:09:44 /nmsio_ena_timemsg

;Enable the NMS Fault Management
2013-223-02:09:44 /LC_SETAPSTATE APNumber=182, NewAPState=PASSIVE
2013-223-02:09:44 /LC_SETAPSTATE APNumber=183, NewAPState=PASSIVE
2013-223-02:09:44 /LC_SETAPSTATE APNumber=184, NewAPState=ACTIVE
2013-223-02:09:44 /LC_SETAPSTATE APNumber=185, NewAPState=ACTIVE
```

Electrical System Model

- Goal 1: Model the State of Charge of The Battery
  - Battery Model
  - Solar Panel Model
  - Switches Model
  - Load Model

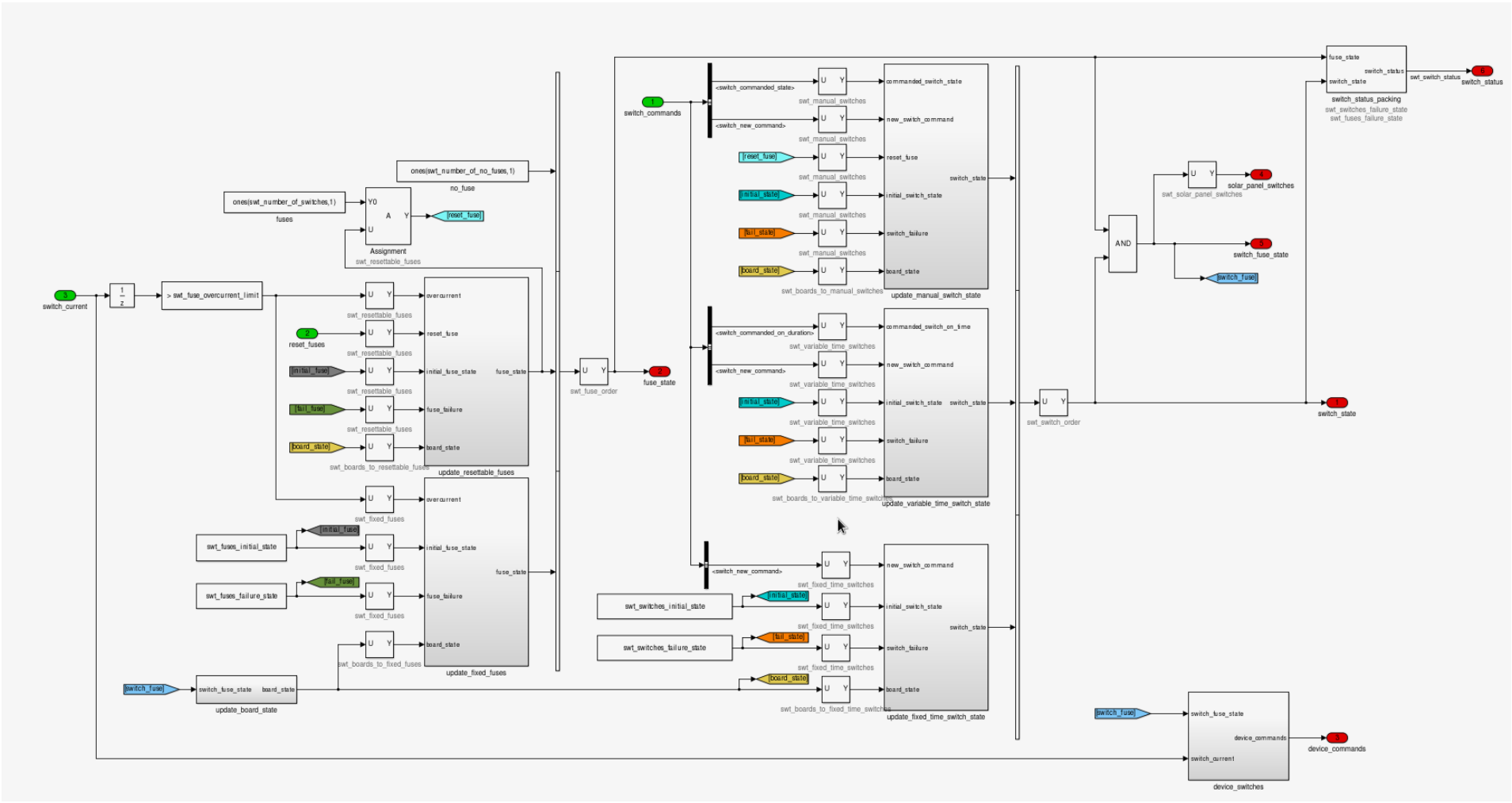


- Goal 2: Model the Switch Command Interface and Current/Voltage Sensor to Support Development and Testing of the Onboard Electrical Load Control Software
- Goal 3: Support Injection of Failures

Electrical System Model

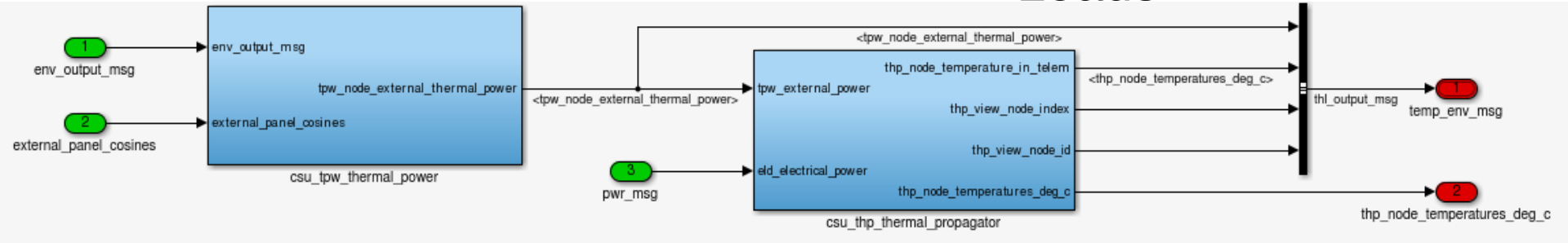
- Implementation
  - Model was developed prior to completion of the design for the electrical system
  - Battery model focused on integration of inflow and outflow of current
  - Solar Panels modeled by section (30 section)
  - Switches, Fuses, Loads model by type and vectorized
  - Designed to automatically reconfigure based on external configuration file
    - Command signal routing to components and back reduced to tables
    - Vectorized component organized in stages
  - Vectorized components built with failure states (on/off)

Electrical System Model



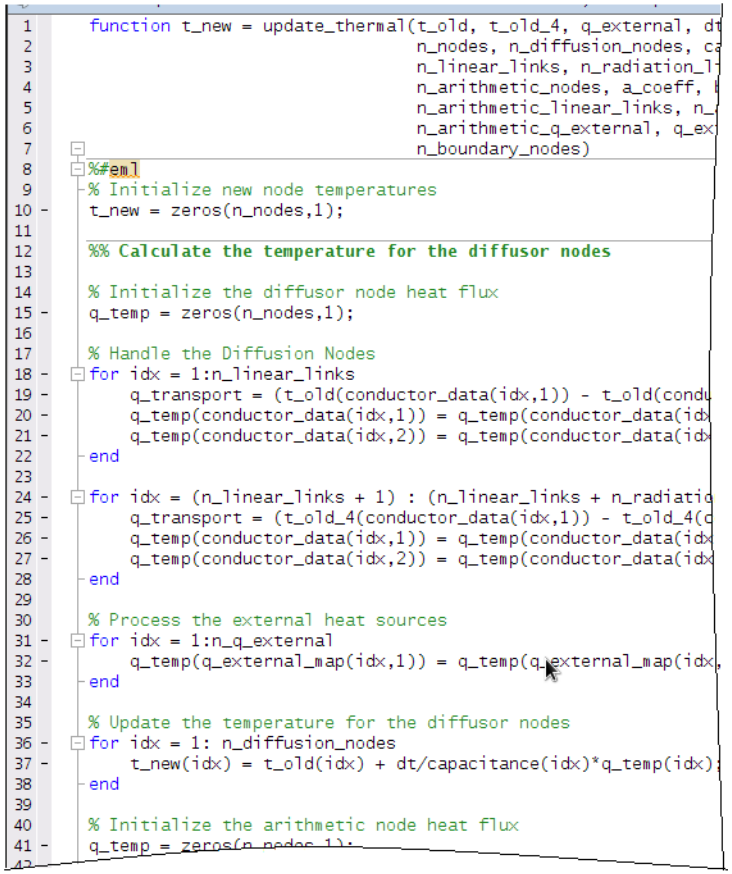
Thermal Model

- Goal: Model The Response Of The Thermal Sensors to External and Internal Heat Sources to Support Development and Testing of the Onboard Thermal Control Software
  - External Heat Sources
    - Sun
    - Moon Radiation
    - Moon Albedo
  - Thermal Propagation
    - Conduction
    - Radiation
  - Internal Heat Sources
    - Heater
    - Loads



Thermal Model

- Implementation
  - Lumped Mass Thermal Model
    - Node and transport properties defined by external file generated by thermal modeling tool
    - Resolution/Fidelity of model determined by input file selection
    - Automatic nodal mapping by node ID to external spacecraft surface, to internal heat sources, and to thermal sensors
  - Thermal Propagation at 10Hz
    - Thermal model input files tested for stability at 10Hz
    - Supported 400+ nodes model propagation in real-time
  - Heat Sources
    - External heat sources tied to vehicle orientation relative to Moon and Sun and eclipses
    - Internal heat sources tied to switch/load currents



Lessons Learned

- Command Interface
  - Development of a parser for STOL scripts for the simulation resulted in single source for test configuration
  - This also enabled the simulation to be used for mission ops training prior to the mission and command validation during mission operations
- Electrical System Model
  - Simplified electrical model was required to maintain real time performance
  - Design modularity and configurability minimized the time spent updating the model to match the actual configuration
  - Fault injection consideration in the initial design enable broad range of training scenario for mission operation personnel
- Thermal Model
  - Lumped mass thermal model proved sufficient for test and training purposes
  - Easy configurability of thermal model allowed user use smaller thermal databases for workstation simulation run that did not require consideration of thermal effects

Lessons Learned

- Overall
  - Multi-Domain simulations can provide broader application opportunities across a life-cycle, thus potentially reducing the cost of maintaining independent specialized tools
  - Multi-Domain simulations can be designed so as to minimize the performance hit by controlling the scope/fidelity of the models associated with each domain